Surface-consistent matching filters: theory and application

Mahdi H. Almutlaq*, Gary F. Margrave

mhalmutl@ucalgary.ca

1. SUMMARY

- This paper presents a new idea for designing a matching filter for processing time-lapse seismic data in a surface-consistent manner.
- We extend the surface-consistent data model to the case of designing matching filters to equalize two seismic surveys in the least-squares sense.
- The frequency-domain surface-consistent design equations are similar to those for surface-consistent deconvolution except that the data term is the spectral ratio of two surveys.
- Since taking spectral ratios poses a challenge, we design the matching filters in a least-squares sense in the time domain and Fourier transform the result.
- We decompose the result into four surface-consistent components: source, receiver, offset, and midpoint.
- Two examples are presented to support this innovation.

2. THEORY

2.1: Surface-consistent model

- The seismic trace can be modeled as:

$$d_{ij}(t) = s_i(t) * r_j(t) * h_k(t) * y_l(t) \qquad (1)$$

d_{ij} : the seismic trace; t is time; and $*$ for convolution

s_i : represent source consistent effect, i source index

r_j : represent receiver consistent effect, j = receiver index

h_k : offset response, $k = |\, i - j \,|$

y_l : subsurface response, $l = (\, i + j\,)/2$

This hypothesis is commonly used to solve: statics problem, deconvolution, amplitude balancing and phase-rotation.

2.2: Matching filters

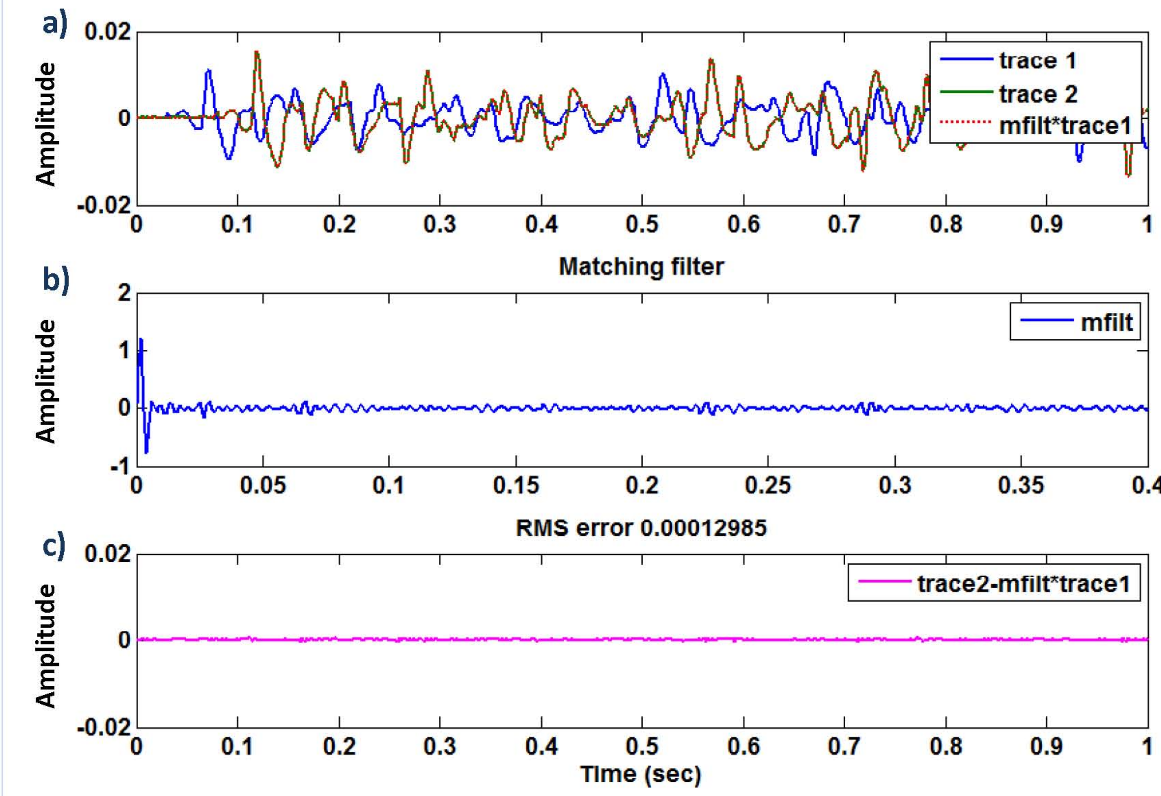

Fig. 1: Two traces (a), their matching filter (b), and residual between trace2 and the matched trace (c).

To match s_1 to s_2:

$$m * s_1 = s_2 \qquad (2)$$

In Fourier domain:

$$M(\omega) = \frac{S_2(\omega)}{S_1(\omega)} \qquad (3)$$

Important remarks:

I. A perfect matching filter is a spectral ratio, however,

II. eqn. 3 is unstable in presence of noise; and

III. its LSQ solution is approximate.

3. CONSTRUCTION OF MATCHING FILTERS

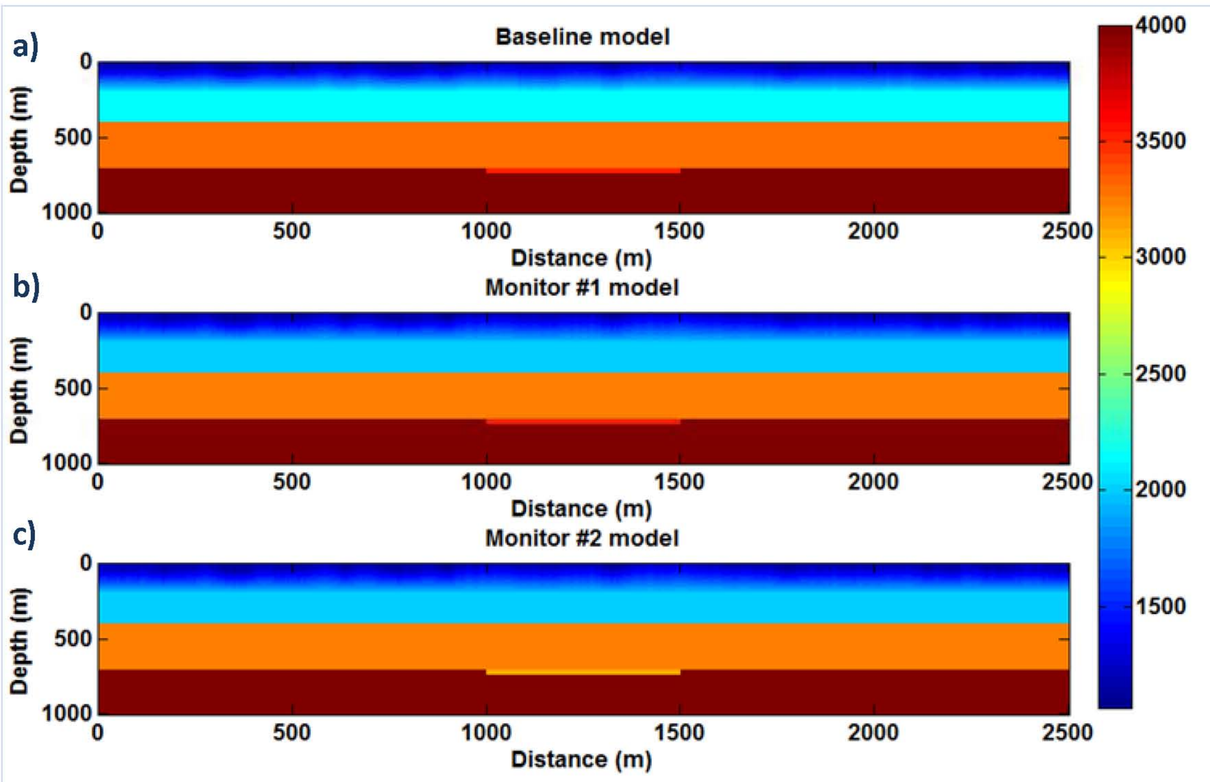

FIG. 2: Baseline model (a) and monitor # 1 model (b) have similar subsurface but differ in near-surface velocity. Monitor # 2 model (c) is similar to (b) except the subsurface (reservoir) is different.

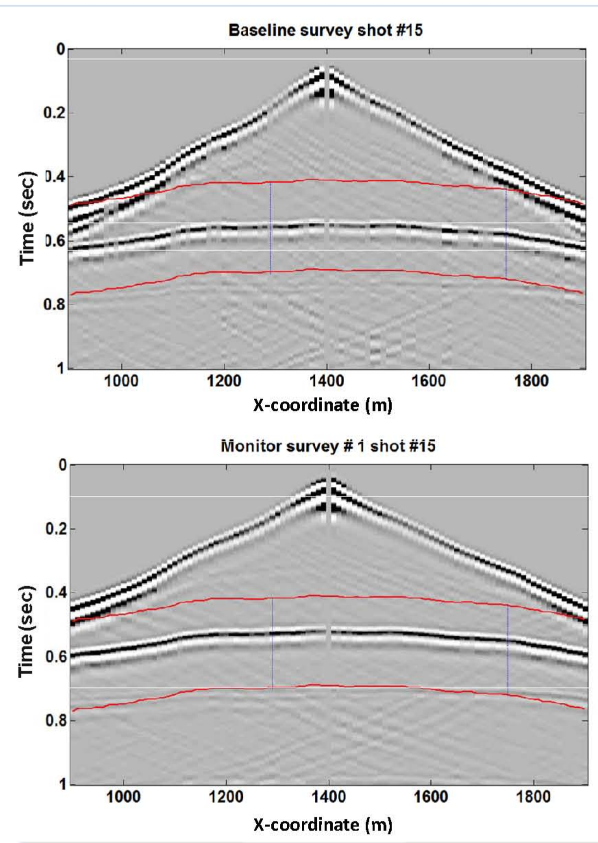

FIG. 3: Input seismic data.

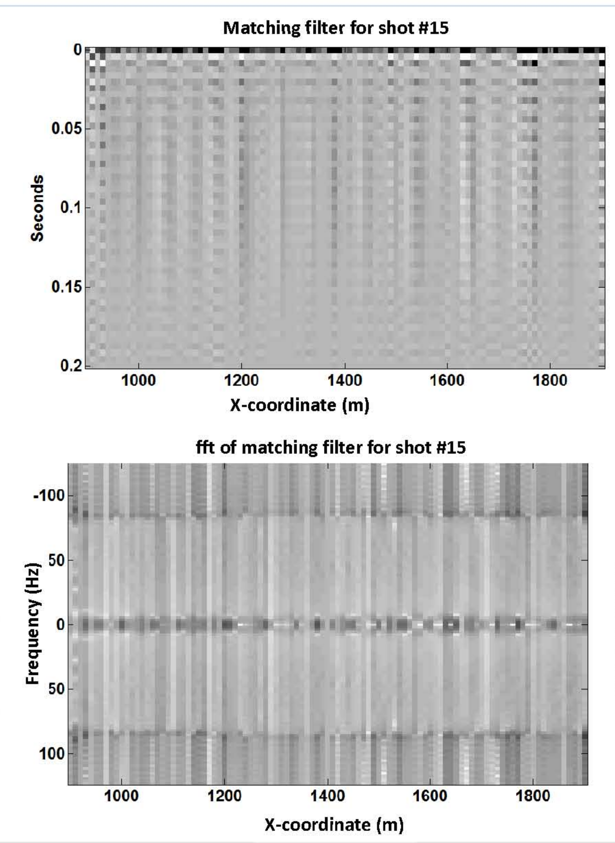

FIG. 4: Matching filters.

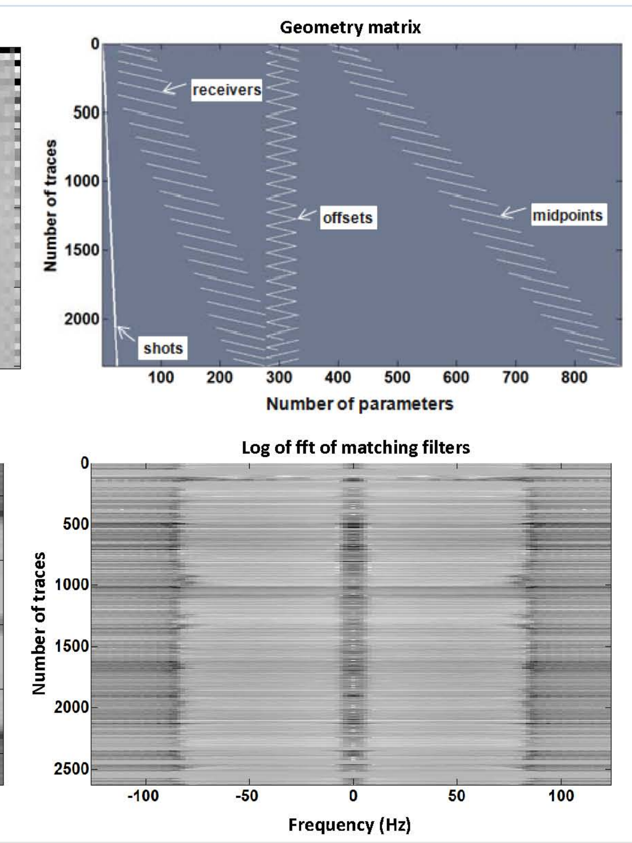

FIG. 5: The log of fft of the matching filters.

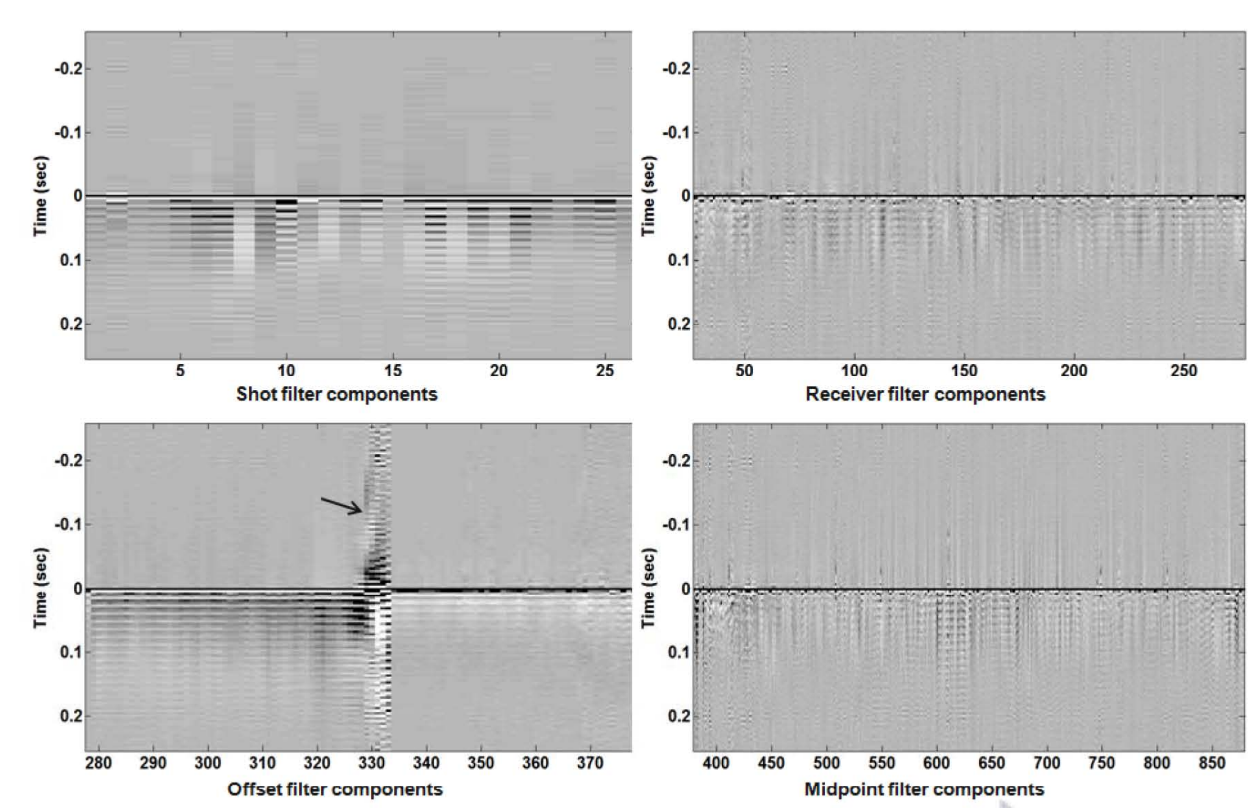

FIG. 6: The four-components filters.

4. EXAMPLES

4.1: Example 1

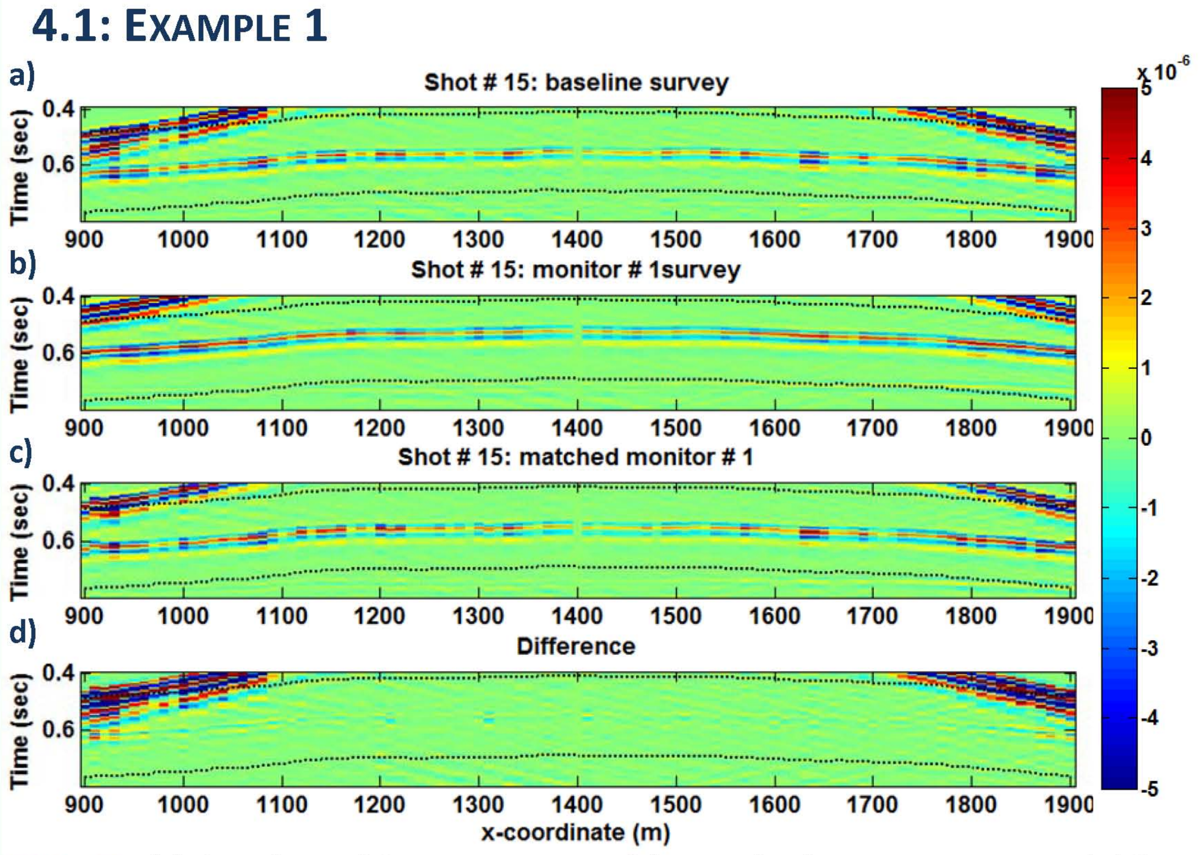

FIG. 7: (a) baseline, (b) monitor # 1, (c) matched monitor # 1, and (d) the difference between baseline and matched monitor.

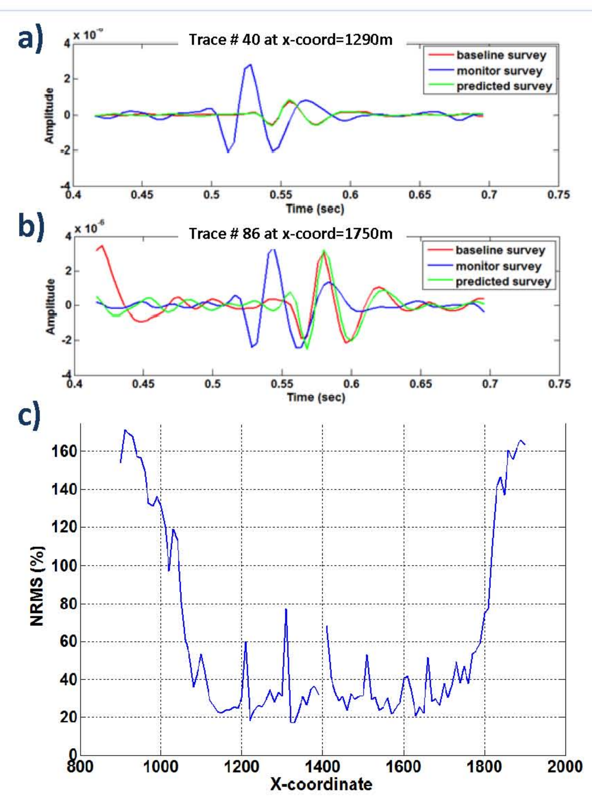

FIG. 8: (a) a comparison of trace #40 from top three shots in Figure 7, and similarly (b) shows trace #86. Nrms values are shown in (c).

4.2: Example 2

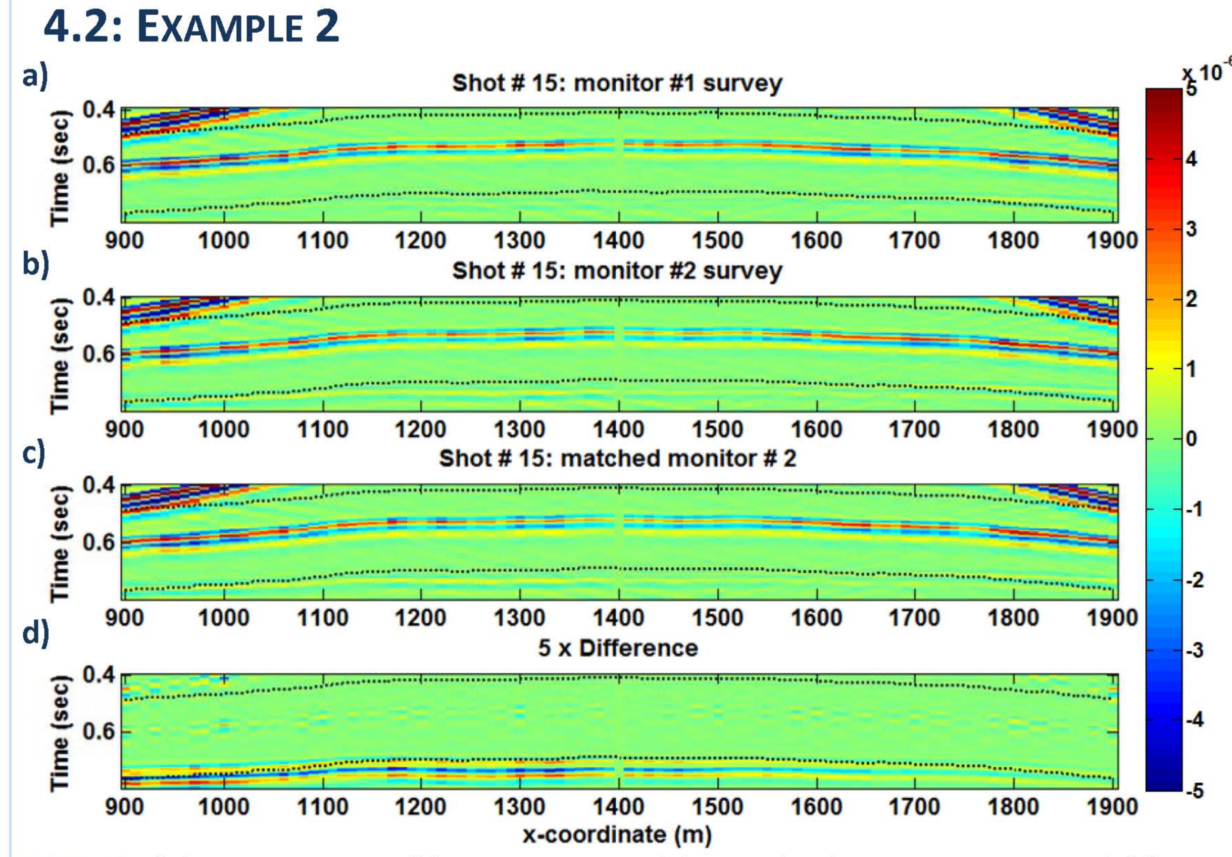

FIG. 9: (a) monitor #1, (b) monitor #2, (c) matched monitor # 2, and (d) the difference between monitor #1 and matched monitor #2

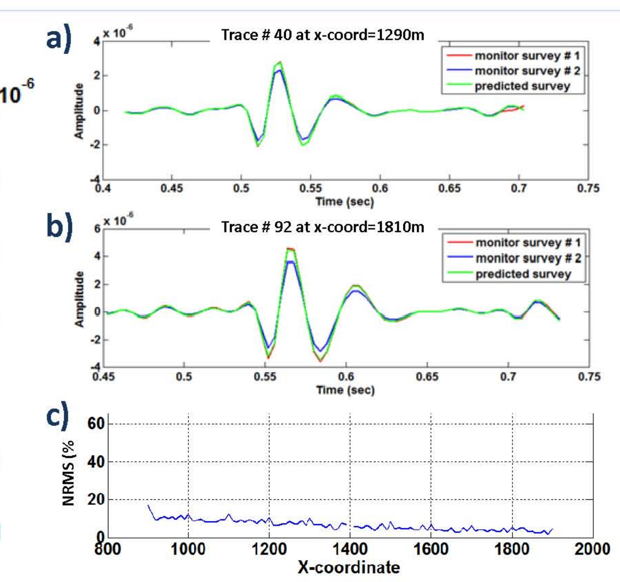

FIG. 10: (a) a comparison of trace #40 from top three shots in Figure 7; similarly (b) shows trace #92. Nrms values are shown in (c).

What is NRMS?

NRMS is a metric measure of the differences in time-lapse data sets. Low NRMS values indicate higher similarities between traces

$$NRMS = 2\frac{RMS(a-b)}{RMS(a)+RMS(b)}$$

(a: baseline, b: monitor)

5. ACKNOWLEDGMENTS

- We thank the sponsors of CREWES for their generous support
- We appreciate all CREWES staff and students, in particular, Faranak Mahmoudian, Hassan Khaniani, Marcus Wilson, A. Naser Yousef Zadeh, Rolf Maier, Kevin Hall, and David Henley.
- Special thanks to Saudi Aramco for sponsoring Mahdi's study program.

References:

Please see Almutlaq and Margrave 2011 CREWES report for complete list of references.